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## PIXEL-LEVEL IMAGE FUSION FOR ARCHAEOLOGICAL INTERPRETATIVE MAPPING

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### Abstract:

This article reports on the current capabilities and future developments of TAIFU, a MATLAB Toolbox for Archaeological Image FUSion. After introducing the need for archaeological image fusion and the benefits it can bring for the interpretation of archaeological image data, the paper briefly explains some of the major fusion methods that are embedded in TAIFU. Afterwards, additional functionality such as metadata tracking and various pre- and post-processing steps are detailed. The paper concludes with a short roadmap of future TAIFU developments.

**Key Words:** distribution fitting, image blending, image fusion, MATLAB, pansharpening, remote sensing

### 1. Introduction

Due to the constant development of new and better imaging sensors working according to different physical principles, the need arises for a meaningful combination of all this imagery. For many years, various research fields have been trying to integrate imaging data of different modalities, not at least in the geoscience and medical communities, to facilitate a better understanding and interpretation of particular phenomena. Also in the field of archaeology and more specifically archaeological prospection, the constant growth in the number and variety of image acquisition techniques creates an increasing demand for image fusion techniques to be incorporated in the analysis of these data.

Image fusion is a process in which the data from two or more images are combined in a specific way, so that a single composite output image is generated. This output image holds specific and/or substantial information from the input images. Ideally, the processing techniques used in image fusion should be efficient and reliable and the newly generated image more comprehensive and thus easier to use for a human interpreter or subsequent processing tasks. In the medical field, image fusion is often used to improve the quality of the original images and to decrease data and information redundancy so that the assessment of medical problems becomes much easier (James and Dasarathy 2014).

In remote sensing, image fusion has been used since the eighties (Chavez, Jr. 1986). The variety of air- and spaceborne sensors that capture the same scene in dissimilar spectral bands and with different ground-sampling distances obviously provides a strong motivation to come up with formal solutions to combine

these data. To enhance the information that can be extracted about that scene, the spectral information from an image with a lower spatial resolution is often fused with the luminance data from a panchromatic image with a higher spatial resolution. This so-called pansharpening procedure yields an image with different spectral bands (i.e. the colour data) as well as a high spatial resolution. Such a pansharpened image is thus an answer to the physical trade-off between spatial versus spectral resolution, since it effectively holds more useful information than could be extracted from a single sensor.

Aside from medical and remote sensing fields, image fusion has also received increasing attention by a wide spectrum of applications such as vehicle guidance or robot vision. Ideally, the fused image holds all redundant information from multiple images and additionally displays the features which are unique for one (or more) of these input images. This newly created image should thus be more suitable for human reading and analysis tasks such as image interpretation. Often, the fused image even reveals information that is not apparent in any of the separate input images. Finally, fusing different image modalities helps in reducing the storage cost.

The fusion of images can take place at different stages. Very often, these different stages are categorized as the signal-, pixel-, feature- and symbolic-level. Here, only methods that work on the pixel-level are considered.

### 2. TAIFU

Since image fusion has hardly been used in any type of archaeological research, a dedicated MATLAB toolbox TAIFU (the Toolbox for Archaeological Image FUSion) has been created. TAIFU serves as a platform for testing

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of well-established and state-of-the-art image fusion methods (see 2.1) and facilitates the development of new data integration routines. This toolbox is thus designed to benefit archaeological interpretive mapping of diverse prospection datasets. For example, the data from a magnetogram can be fused with an aerial image to aid the archaeologist in correlating feature locations for a more trustworthy information extraction and better interpretation of the hidden geo-cultural landscape.

## 2.1. Incorporated fusion methods

The following section presents a short overview of the various image fusion approaches that are presently embedded in TAIFU (version 0.2). Three big families of methods will be explained in slightly more detail.

### 2.1.1. Blending modes

In many popular image editing programs such as Photoshop (Adobe), GIMP (Open Source) or Pixelmator (Pixelmator Team), the user can choose between several blending modes. These modes, which are often denoted as layer modes, change the appearance of the upper layer or image (called blend layer) based on the base image(s)/layer(s) beneath it. As such, blending modes can also be seen as image fusion algorithms.

TAIFU incorporates all (except the useless “Dissolve”) blending modes which can be found in common image processing applications and even offers several others which are not found amongst the biggest players in the image editing world (Fig. 1). Because TAIFU converts all input images to double-precision floating-point numbers in the range [0, 1], no extra normalisation step is needed when working with conventional 8-bit or 16-bit images.

Blending method	PhotoShop CC	Pixelmator 3.4	GIMP 2.8	TAIFU 0.2
Normal	X	X	X	X
Average				X
Interpolate				X
Dissolve	X	X	X	
Darken or Minimum	X	X	X	X
Multiply	X	X	X	X
Colour burn or Burn	X	X	X	X
Soft Burn				X
Linear burn	X	X		X
Darker colour	X	X		X
Lighten or Maximum	X	X	X	X
Screen	X	X	X	X
Colour dodge or Dodge	X	X	X	X
Soft dodge				X
Linear dodge / Add(ition)	X	X	X	X
Lighter colour	X	X		X
Overlay	X	X	X	X
Soft light	X	X	X	X
Hard light	X	X	X	X
Vivid light	X	X		X
Linear light	X	X		X
Pin light	X	X		X
Hard mix	X	X		X
Difference	X	X	X	X
Exclusion	X	X		X
Subtract	X	X	X	X
Grain extract			X	X
Grain merge			X	X
Divide	X	X	X	X
Reflect				X
Glow				X
Freeze				X
Heat				X
Negation				X
Phoenix				X
Stamp				X
XOR				X
AND				X
OR				X
Hue	X	X	X	X
Saturation	X	X	X	X
Colour	X	X	X	X
Luminosity (or Value)	X	X	X	X

**Figure 1:** Overview of the different image blending methods that can be found in popular raster editing programs.

### 2.1.2. Pansharpening

It was already mentioned above that pansharpening is an approach in which the spatial information of a high resolution panchromatic image is integrated with the spectral information from an image with a lower spatial resolution. Panchromatic fusion can be accomplished by several techniques. So far, TAIFU embeds IHS (Intensity Hue Saturation) pansharpening (the original IHS method as well as the adaptive IHS approach – Rahmani *et al.* 2010), wavelet-based pansharpening, Principal Component Analysis (PCA) and Brovey pansharpening. In addition, the user can choose to (de)active image histogram matching and channel normalisation.

### 2.1.3. Distribution fitting

Distribution fitting creates an  $N$ -band image from the input images (e.g. two three-band images deliver a six-band image). Afterwards, a histogram is computed for every image pixel (i.e. for the six-band image, a pixel-specific histogram is computed from the six samples). The user then defines a theoretical Probability Density Function (PDF) which is fitted to every pixel-specific histogram. Since every PDF is defined by one or more parameters, the parameters that define the fitted PDF for that pixel can be saved and form the new pixel values. More information about this method can be found in Doneus *et al.* (2014). TAIFU offers several discrete and continuous PDFs for uni- or bimodal fitting. Multi-threading (interactively customisable) is also exploited.

### 2.1.4. Additional fusion approaches

Aside from these three big families of fusion approaches, many other methods have been implemented: (weighted) PCA fusion; ICA or Independent Component Analysis-based fusion (see Fig. 2), (discrete stationary) wavelet-based fusion, logistic weighting, guided-filtering (Li *et al.* 2013) and gradient domain fusion.

## 2.2. Other functionality

TAIFU is currently coded in such a way that the user has to load two images (Fig. 2). Upon import, the toolbox verifies and stores the metadata of the images (such as georeferencing, Exif and IPTC tags). In addition, the user has a variety of pre-processing steps at his/her disposal: individual image channels and their histograms can be viewed and extracted, various (perception-based) colourmaps can be used to colour-code single band imagery and a handful of contrast enhancement algorithms can make certain image features better perceivable. Moreover, colour-to-greyscale (and vice versa) conversions allow to fuse imagery for which the fusion method expects an (un)equal amount of bands.

In a next step, the above-mentioned fusion methods (often with additional options such as alpha values) can be chosen to create a fused output. When a useful result is obtained, the fused image can be saved with all the metadata embedded, although the latter can also be stored as a sidecar ASCII file. These new metadata originate from both input images, but they also contain data about the contrast enhancement(s), colour-map(s), channel-conversion(s) and fusion algorithm(s) that were used to obtain the final result. All abovementioned steps can be fully batched as well. Finally, all buttons feature (deactivatable) tooltips, all fusion methods come with

explanations and a separate notification window informs the user about on-going and possible processes (Fig. 2).

### 3. Future additions and improvements

For the next release (0.3), many additional capabilities have been planned. TAIFU 0.2 only accepts single band or three band images. From version 0.3 onwards, multi-band imagery will be supported. This, however, means that many image fusion and contrast enhancement algorithms will have to be reprogrammed so that they are flexible enough to deal with a varying amount of input bands. Second, version 0.3 will provide various image metrics that can hopefully reliably assess the quality of the fused output. Third, a few processor intensive methods will be ported to C++.

TAIFU 0.4 will be capable of interpreting several coordinate reference systems (CRSs) and offer some simple tools for dealing with images that are not perfectly co-registered or those that are expressed in dissimilar CRSs. Moreover, the possibility to interpret CRSs will make it possible to automatically or manually extract the overlapping part of the images. In this way, TAIFU will

be able to deal with datasets that have a varying spatial extent and feature dissimilar spatial resolutions, something that is currently not supported.

Finally, it is hoped that TAIFU 0.4 can be released free-of-charge or at a very moderate cost, but negotiations concerning this issue are still on-going.

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**Figure 2:** The main TAIFU window. A digital terrain model (upper left) is fused with a magnetogram (lower left) using ICA-based fusion.

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